THE COMPARATIVE PHYSICAL AND CHEMICAL PROPERTIES OF AN ALKALI SPOT AND AN ADJOINING NORMAL SOIL

by

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INTRODUCTION

Soil alkali presents a serious problem in agriculture at the present time. It is particularly an important problem in irrigated regions. Vast areas of land, which once were fertile and productive, have been abandoned because of alkali accumulation. In the United States, as reported by Harris (13), about 13 per cent of irrigated land contains sufficient alkali to be seriously harmful to crop growth. This alone amounts to over nine million acres of land and does not include those areas which are not under irrigation but are affected with alkali. Similar figures are available from other countries indicating the importance of the subject.

Soil containing injurious quantities of alkali are found on every continent. The distribution of these soils, however, is confined to areas where conditions are favorable to their formation. The most important of these conditions are aridity and the presence of sodium salts in the soil.

Very often alkali is localized in small areas of soils developed under a humid climate. These areas are known as "alkali spots" or "slick spots." They are ordinarily scattered in the field and usually occur either in depres-

sions or at the sides or heads of draws. They may be recognized as white or light gray spots with scanty vegetation, if any, surrounded by productive land. The formation of these spots has generally been attributed to the seepage of ground water. Such seepage may be lateral or vertical in direction, or both.

In Kansas there are spotted areas of soil developed under humid or sub-humid conditions that scarcely support plant growth. These spots occur chiefly on the slopes, on terrace lines, and in the depressions. They vary greatly in their size, physical properties and in their chemical composition.

The experimental work reported in this paper is an attempt to determine some of the fundamental differences that exist between a "slick spot" and the surrounding normal soil. In order to accomplish this purpose, profile studies, chemical and mechanical analyses, and greenhouse experiments were conducted with "slick spot" soil and adjoining normal soil.

REVIEW OF THE LITERATURE

Origin of Alkali

The presence of alkali deposits over the surface of soils was observed long before scientists were able to

account for the origin of these salts. Even at the present time opinions differ as to their mode of formation. There are several theories that have been advanced and only the more important ones will be mentioned here.

Hilgard (20) relates the origin of alkali to ordinary weathering of rock materials under conditions of aridity. It is a well established fact that all soils largely consist of rock particles and that almost any rock is rich in alkali salts. Where rainfall is abundant, a large portion of these salts is leached and carried away. Under arid conditions, on the contrary, the entire amount of salts remains in the soil and capillary movement of ground water followed by evaporation keeps them accumulated on the surface. This theory was later supported by Glinka (11).

The parent materials from which the soils are derived are regarded as probable sources of alkali salts in the soil. Dorsey (8), in Montana, mentioned shales and sandstones as sources of alkali in soils of some regions. In their extensive geological studies in Utah, Colorado, Arizona, Wyoming, Idaho, and Nevada, Stewart and Paterson (38) have observed the presence of large quantities of alkali salts in country rocks from which these soils were formed.

The origin of alkali has also been attributed to the materials deposited from some ancient seas. Vilensky (40)

proposed that salinity of soils is due to the residues of salines formed at the time of drying from the earth's surface of waters of the last glaciation under the influence of postglacial climate.

Robinson (34) and de Sigmond (36) are of the opinion that salification may take place by a rise in the level of salt-bearing ground water. This may take place naturally in some places, but more frequently is developed by improper handling of soils. It has been reported that in the San Joaquin Valley of California, the water table was once 65 feet below the surface and the soil was practically free of salts. As a result of irrigation without adequate under-drainage, the water table rose up to 2-3 feet below the surface and the soils became affected with alkali.

The principle involved in the formation of carbonate of soda in soils is purely an exchange of bases. This hypothesis is universally understood, but there are differences of opinion as to the types of reaction that take place with the resultant formation of sodium carbonate.

Hilgard (20) explained the formation of Na_2CO_3 by the interaction of chlorides and sulfates of sodium with calcium carbonate in the soil in the presence of water. Gedroiz (9), on the contrary, concluded that Na_2CO_3 is not formed by the direct reaction between NaCl and $CaCO_3$, but

that the sodium of the chlorides replaces other bases (calcium and magnesium) in humates and silicates and the latter give up soda when the excess of soluble sodium salts is removed.

The theory of Dominicis, as pointed out by Joffe and Mclean (22), is similar to that of Gedroiz. According to this theory the hydrogels formed by the replacement process in certain silicates and humates change into hydrosols. Hydrolysis of the sodium complexes takes place with the formation of NaOH, which absorbs CO_2 from soil water and forms Na_2CO_3. In this respect he differs from Gedroiz, since the latter believed that $CaCO_3$ is essential for the formation of sodium carbonate. The work of Cummins and Kelley (5) in California and Breazeale and McGeorge (4) in Arizona substantiate the hypothesis of Dominicis. They concluded that the formation of alkalinity is due to the hydrolysis of sodium silicates with the formation of NaOH. The hydroxide of sodium thus formed is readily converted into sodium carbonate by the CO_2 of the soil solution.

Two theories have been proposed concerning the origin of nitrates in the "niter spots" found in Colorado and other western states. One is that of Headden (14, 15) and Sackett and Isham (35) who believed that these nitrates were formed within the soil by the action of non-symbiotic nitrogen

fixing bacteria. The idea is advanced that nitrogen is fixed from the air and later oxidized to the nitrate form. The other theory is that of Stewart and Paterson (37, 39) who stated that the surrounding shales are comparatively rich in nitrates and that the accumulation is a leaching and seepage process.

Kinds of Alkali

Alkali soils have been divided into (a) "white alkali" and (b) "black alkali," depending upon the quality of the accumulated salts. This differentiation was first made by Hilgard (20) and is commonly accepted by American writers. Alkali consists of four principal types of salts, namely, chlorides, sulfates, carbonates, and bicarbonates of the various bases. During dry periods, as a result of evaporation, the sulfates and chlorides of alkali show efflorescence on the surface of the soil from which the American term "white alkali" is derived. On the other hand, where hydrolysis of the sodium clays has resulted in the formation of NaOH, the corrosive action on vegetable matter produces a brown or black deposit on the surface of the soil, which has given rise to the name "black alkali." Black alkali is more destructive to plants than white alkali.

Another commendable classification of alkali soil has

been made by Russian investigators (9, 10, 11, 40). In this classification, alkali soils are divided into two major groups - the Solonchak and the Solonetz. The former most nearly represents the white alkali of the American writers although it is a broader classification designating not only the soils with high soluble salt content and low alkalinity but definite, pronounced physical properties as well. Solonetz most nearly represents the black alkali soils as designated by Hilgard, but signifies a soil with low soluble salt content, high content of replaceable sodium, and, as a result of hydrolysis of these sodium complexes, high alkalinity. The high alkalinity results in solution of organic matter and the consequent formation of the brown or black crusts from which the designation "black alkali" is derived.

The outstanding features of alkali type in general as reported by Gedroiz (9, 10) and Glinka (11) in Russia, de Sigmond (36) in Hungary, and Hilgard (20), Kellog (28), and Nikiforoff (32) in the United States, are either a relatively high content of soluble salts or the presence of much sodium in exchangeable form. The sodium plays an important role in altering the physical properties of soils due to its deflocculating action. The absorbed sodium raises the dispersity of the absorbing complex of the soil

with the consequent development of compactness, impermeability for water and stickiness of soil horizons.

The profiles of Solonchak (saline or white alkali) soils are characterized by an excess of soluble salts and the colloids are saturated partially with divalent and partially with monovalent cations. Among the latter may be some sodium. Excess of soluble salts prevents the hydrolysis of sodium from the exchange complex and keeps the colloids flocculated. There is no definite distribution of salts through the horizons. At times the maximum concentration of salts occurs at or near the surface and at other times they are more concentrated at some distance below the surface. Usually the more readily soluble salts are concentrated near the surface and decrease downward while, on the contrary,the less soluble salts are of low concentration near the surface and increase downward. The specific character of the soil, however, depends on the position of the water table, the amount and distribution of the rainfall, the concentration and composition of the soluble salts, and the general character of the soil of the region. The Solonchak soils are not strongly alkaline because the excess of soluble salts prevents hydrolysis of the sodium bearing complexes.

The Solonetz (black alkali) soils are characterized by

a low content of soluble salts. The exchange complexes are largely saturated with bases of which sodium constitutes a high percentage. Because of hydrolysis of these sodium complexes, high alkalinity is developed. This produces a high dispersion of the colloidal matter and the soil becomes extremely sticky and tenacious when wet and very hard when dry. They exhibit impervious horizons with little or no structural development. Such structure as is developed has been described as pillar, prismatic, columnar, or blocky. The lack of structure of alkaline soils is due to the deflocculated state of the colloidal fraction. The soil is not stable and it undergoes rapid degradation under the influence of exchangeable sodium, which is directly or indirectly responsible for the deflocculation of the colloids.

Reclamation of Alkali Soils

The reclamation of alkali lands depends chiefly upon either the removal of soluble salts or the conversion of sodium clays into calcium clays or both of these processes. Several methods have been employed, both in the United States and in Europe, and some of these have promised to be very satisfactory. No single method of reclamation is, however, adapted to all alkali lands. Many conditions must be considered before deciding upon the advisability of re-

claiming a given area of land and the methods to be used in case reclamation appears to be economical. The alleviative measures which may be employed in dealing with alkali problems are as follows:

1. Cultivation of alkali-resistant crops
2. Reduction of evaporation
3. Removal of soluble salts
4. Application of chemical substances accompanied or unaccompanied by leaching.

According to Hilgard (20), Harris (13), Dorsey (6, 7), and others, certain crops are capable of enduring large quantities of alkali salts. This would be the simplest method of reclamation provided crops could be found that would grow on all classes of alkali soils, but unfortunately only a few such crops have as yet been found and they do not flourish on all alkali soils. Allowing the land to remain uncropped promotes accumulation of alkali through excessive evaporation at the surface with no removal of salts. It is desirable, therefore, to maintain some kind of plant growth on the land even though the plants grown are not the most desirable.

Since evaporation of the soil moisture brings the salts to the surface where the main injury to plants occurs,

it is important to prevent evaporation as much as possible. Hilgard (20) proposed three methods for checking evaporation, namely, shading, mulching, and loosening the surface of the soil. Shading simply prevents direct evaporation from the soil surface. When the moisture is absorbed by the plants, it is given off by the leaves and the salts accumulate in the plants, thus the salt content of the soil is diminished if the plants are removed. Alfalfa, when once established, serves this purpose very well. Experimental work in California indicates that mulching is an effective remedy in soil not heavily affected by alkali. This method can be applied only when perennial plants such as trees are grown. Fruit trees are often protected by this method. de Sigmond (36) in Hungary has found this method very effective in some cases. Good tilth can be maintained by good preparation and thorough and frequent cultivation of the land. An unstirred soil forms a crust which acts as an excellent conductor of moisture. Breaking up this crust is important in checking evaporation.

Among the methods proposed for removing soluble salts from the soil, leaching the alkali out of the soil has been considered the most satisfactory. This method has been in practice for a long period of time and in some instances produced satisfactory results. The general opinion during

the early history of reclamation efforts was that removal of soluble salts by leaching would overcome the toxic condition of the soil. Numerous instances may be cited (5, 26, 27) to show that in case of soils with a high percentage of sodium, leaching alone is not a satisfactory measure. The sodium in such soils reacts with the base-exchange complex, replacing calcium and magnesium, forming simple salts of these bases and sodium-exchange complex. Thus, after the excess of soluble salts has been leached out, the replaceable sodium becomes toxic to plants and deflocculates the soil. Therefore, according to Kelley and Arany (27) a successful reclamation requires not only the removal of soluble salts, but the displacement of at least a part of the replaceable sodium from the exchange complex.

The use of chemical substances, such as gypsum and sulfur, has thrown an important light on the reclamation of alkali soils. Hilgard (20) recommended the application of gypsum in the reclamation of black alkali soils. The California Experiment Station (5, 24, 25, 26, 27) has presented evidence showing the pronounced effect of gypsum in such a process. The results obtained by several other investigators (11, 19, 23, 36) are in agreement with those obtained in California. Headden (16, 17) in Colorado suggested the use of nine pounds of gypsum for each pound of black alkali

in the soil and the removal of alkali by surface irrigation. Kelley and Thomas (26) in their extensive work on black alkali reclamation have come to the conclusion that gypsum when applied at the rate of 10 tons or more per acre and accompanied by leaching is very effective.

Lipman (30) in his experiments on sulfofication suggested elemental sulfur as an effective means of alkali land reclamation. Hibbard (18) published data which support the work of Lipman. The results found by Kelley and Thomas (26) in California and Johnston and Powers (23) in Oregon indicate the importance of sulfur as a reclaiming agent. It has been stated by Kelley and Arany (27) that with soil low in $CaCO_3$ content, sulfur alone is not very satisfactory. Under such conditions as reported by Kelley and Thomas (26), sulfur in combination with lime or stable manure has been very successful. Experimental results, in general, show that heavy applications of sulfur alone may produce good results provided the soil is not rendered too acid by such treatment.

Materials such as iron sulfate and alum have also been used in reclamation projects with successful results. The data obtained in California (26, 27) indicate the pronounced effect of the use of these materials on soils. Johnston and Powers (23) have noticed the marked improvement in the

physical condition and the increase in crop-producing power of soils produced by the application of iron sulfate and alum. A heavy application of these materials is required in order to bring about the desired results.

In a series of greenhouse experiments with barley, Lipman and Gericke (31) have observed marked changes in soils produced by the application of stable manure unaccompanied by leaching. In California (26, 27) the use of manure in combination with gypsum or sulfur followed by leaching has been decidedly beneficial. Johnston and Powers (23) have stated that manure alone has not been effective in reducing the black alkali although it has resulted in an improvement of the tilth and permeability of the soil. de Sigmond (36) in Hungary concludes that the use of manure results in a temporary improvement in alkali soils, which makes it possible to start crops on such land.

MATERIALS AND METHODS

Profile Studies

A typical alkali spot, such as occurs in numerous locations in the soils of the humid parts of Kansas, was chosen for investigation. This spot, about one-twentieth acre in size, is located in Field 3, Block B of the Agronomy Farm of the Agricultural Experiment Station. One of the

objects of this investigation was to make a thorough observation of the physical condition of this barren soil, often referred to as "slick spot," as compared to the surrounding normal soil. In order to do this, two holes were dug, one in the "slick spot" and the other in the normal soil about 50 feet apart. The various horizons were differentiated and the depth, color, texture, structure, and other general characteristics of each layer were noted. Samples were collected from each profile and were taken to the laboratory for chemical and mechanical analyses. Also samples of the surface six inches of each, the normal soil and the "slick spot," were taken to the greenhouse for cropping experiments.

Laboratory Investigations

All determinations were duplicated in order to increase the accuracy of the analysis. In some instances, particularly in cases of magnesium and sodium determinations, the samples were analyzed in triplicate. Total soluble salts, total exchangeable bases, exchangeable calcium, exchangeable magnesium, exchangeable potassium, exchangeable sodium, total nitrogen, organic carbon, and pH values were determined on the unfractionated soil. The SiO_2, R_2O_3 content and the base-exchange capacity of each of the colloid fractions

were also determined. The procedures used were as follows:

A. Soluble salts. The soluble salts were determined by shaking 100 grams of soil with 500 cc of distilled water for one hour, filtering and evaporating an aliquot of the filtrate to dryness in a weighed evaporating dish. The residue was ignited in the muffle furnace at low red heat for at least one hour, cooled in a dessicator and weighed. Soluble salts were reported as parts per million of the dry soil. Qualitative tests for each of the various soluble constituents were also made.

B. Replaceable bases. Total replaceable bases were determined by the method of Kappen in which a 25-gram sample of soil is treated in an Erlenmeyer flask with N/10 HCl, shaken at intervals for 20 minutes and filtered on a Büchner funnel with slight suction. An aliquot of the filtrate is removed and titrated with N/10 NaOH using Brom Thymol Blue as indicator. For determination of the individual exchangeable bases, a 10-gram sample of soil was shaken in an Erlenmeyer flask with 50 cc of N/20 HCl, the suspension transferred to a Büchner funnel and filtered with light suction. The sample on the filter was leached with successive portions of N/20 HCl until 500 cc of leachate were obtained. The bases were determined in the leach-

ate and reported as milligram equivalents per 100 grams of air-dry soil.

In the determination of replaceable sodium the uranyl zinc acetate method as described by Bray (2) was used. The perchlorate method was employed in the exchangeable potassium determinations.

Calcium was precipitated as the oxalate and determined volumetrically by titration with $KMnO_4$. The method used for the determination of replaceable magnesium was the volumetric method proposed by Handy (12).

The Gunning-Hibbard method was used in the determination of total nitrogen in the soil. The ammonia was distilled into boric acid and titrated with H_2SO_4 using a mixture of methyl red and brom-cresol-green as indicator. The total nitrogen was reported as percentage of the air-dry soil.

In the determination of organic carbon, the wet oxidation method was used. The CO_2 was absorbed in NaOH, precipitated as $BaCO_3$ and the excess alkali titrated with HCl, using phenolphthalein as indicator.

Having found the percentage total nitrogen and the percentage organic carbon in each sample, the carbon-nitrogen ratio was calculated.

Reaction of each soil sample was determined with the

quinhydrone electrode.

C. SiO_2 and R_2O_3 content and base exchange capacity of soil colloids. The colloid fraction was separated from a soil sample from each horizon of the two profiles by churning 200-400 grams of soil with four liters of distilled water in an end-over-end churn for two hours and allowing the sand, silt, and coarser clay particles to settle out for another two hours. At the end of this period the supernatant liquid was siphoned off and centrifuged for 20 minutes in order to throw out of suspension any particles above colloidal size not previously removed. The liquid in which the colloids were dispersed, was then filtered with a Pasteur-Chamberland pressure filter. The colloids were washed out in a beaker and evaporated to dryness on the steam bath. Sufficient colloid was thus obtained for analysis for SiO_2, R_2O_3, and base exchange capacity.

The SiO_2 and R_2O_3 contents of the colloid samples were determined by fusing one-half gram of well-pulverized colloid with Na_2CO_3. After dehydration of the silica it was removed by filtration, ignited, and weighed. The R_2O_3 constituents were precipitated in the filtrate with NH_4OH, filtered, ignited, and weighed. Both SiO_2 and R_2O_3 were expressed as percentage of the oven-dry colloid.

In the determination of base-exchange capacity of the colloid, two grams of colloid were leached with neutral ammonium acetate and the excess salt was washed out with 80 per cent ethyl alcohol. The colloid was then transferred into a Kjeldahl flask with distilled water and after addition of MgO, the ammonia was distilled into boric acid and titrated with H_2SO_4. The base-exchange capacity was reported as milligram-equivalents per 100 grams of colloid.

D. Mechanical analysis. In addition to the chemical analysis, all samples were analyzed mechanically. The pipette method as described by Olmstead, Alexander, and Middleton (33) was used. The soil fractions were reported as percentage of the total mineral portion of the soil.

DESCRIPTIONS OF THE SOILS

Normal Soil

The soil is a silt loam and although not recently correlated, probably belongs to the Derby series. The surface soil is dark brown, changing to light brown or to reddish brown in the subsurface and becomes distinctly reddish brown in the subsoil. The soil is relatively friable throughout its depth. The structure of the surface soil is slightly granular. The horizons are well defined with distinct lines

of demarcation. The subsoil is heavier and more compact than the surface soil, but there is no hint of clay pan development. The surface soil is slightly acid and of moderate fertility. The subsoil is neutral or slightly alkaline. A detailed description of the various horizons is given below, and a photograph of the profile is shown as Plate I.

A. 0"- 9" Dark brown silt loam, largely structurless but with some aggregation in the lower half of the horizon. Thoroughly permeated with plant roots. No effervescence with HCl.

B_1. 10"-21" Light brown to reddish brown with soft crumb structure, slightly columnar. Texture, silty clay loam.

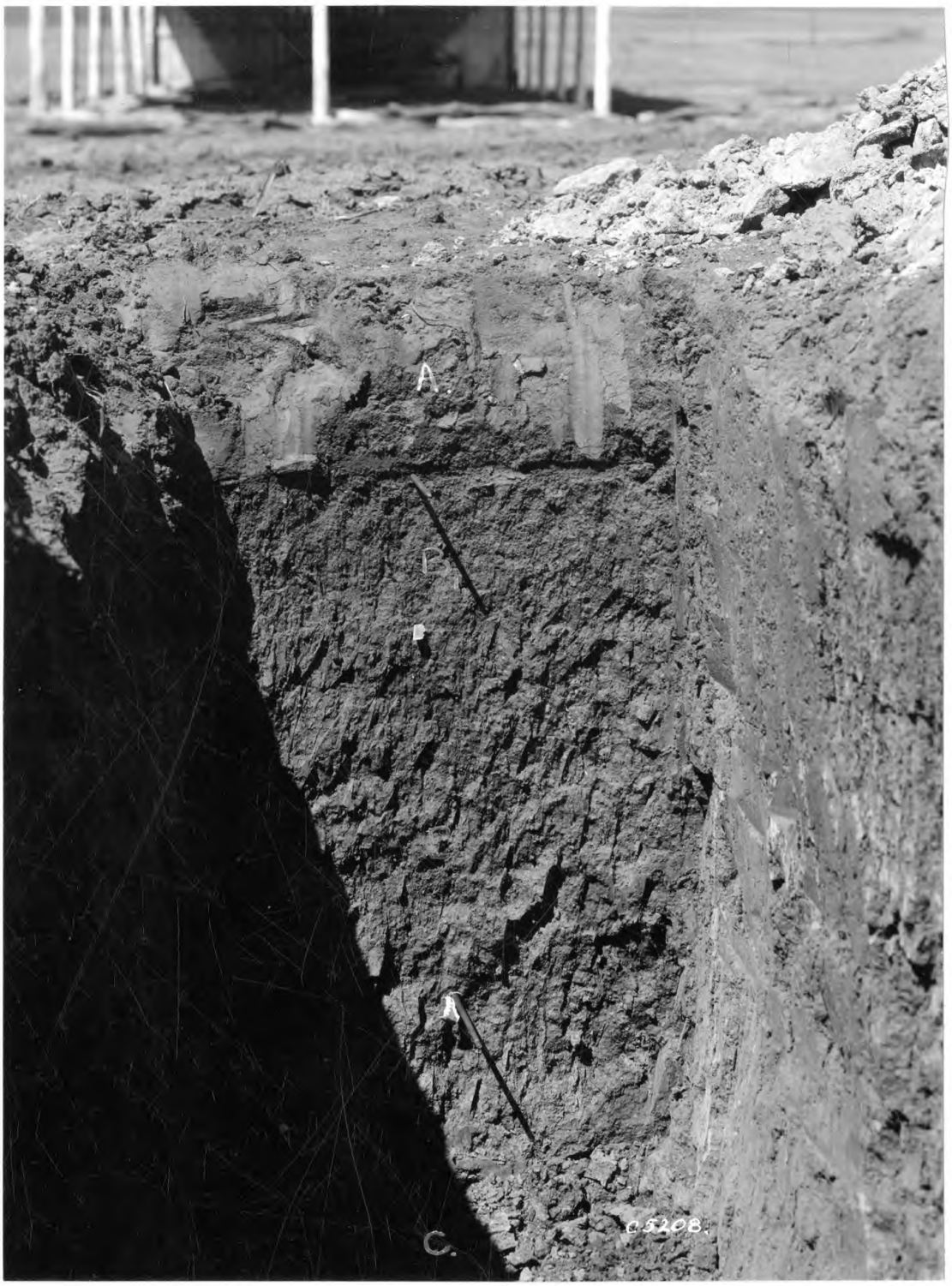
B_2. 22"-36" Reddish brown, less compact and less heavy than B_1. Slightly mottled and containing some small concretions of $CaCO_3$. The soil is more friable than B_1. Texture, silt loam. Structure, slightly columnar.

C. 36"+ Parent materials. Fairly uniform, calcareous wind deposits. Texture, silt loam. Color, light-reddish brown. Almost no mottling present. $CaCO_3$ concretions rather numerous. Fairly friable. Effervesces with HCl.

Plate I

Photograph of the Profile of the Normal Soil.

PLATE I



"Slick Spot"

The profile of the "slick spot," although located within 50 feet of the normal soil profile, is distinctly different from the latter. The profile development is influenced by the seepage of ground water and the profile has some of the characteristics of a solonetz soil, that is, low soluble salt content, relatively high alkalinity, and a deflocculated condition. A striking feature of the appearance of this soil is a very thin whitish crust at the surface of the soil which produces a "slick" appearance when wet and slight efflorescence when dry. Water enters into the soil with considerable difficulty because of the compact nature of the surface soil. In reality the surface soil, which is described as the A horizon, resembles much more the B horizon of a strongly leached normal soil than the surface layer of such a soil. The heavy surface soil is underlaid by a still heavier, impervious layer, a true hardpan. This layer is hard and difficult to penetrate when dry and extremely sticky and plastic when wet. Beneath this layer are the parent materials, light gray in color and very friable. The soil is very unproductive, is moderately alkaline in the surface, and fairly strongly alkaline in the subsoil. A detailed description of the

various horizons follows and a photograph of the profile is shown as Plate II.

A. 0"- 6" A shallow surface horizon. Color, medium brown, being somewhat lighter than A of the normal soil. Structure, irregular in nature, cloddy, or blocky owing to a considerable dispersion of soil particles. The structure particles are coated with a brown stain, producing a considerable degree of induration. The brown color, although similar to that produced by Fe_2O_3 and $Fe(OH)_3$, is in reality due to soluble organic matter. Texture, sandy clay loam. Slight effervescence with HCl.

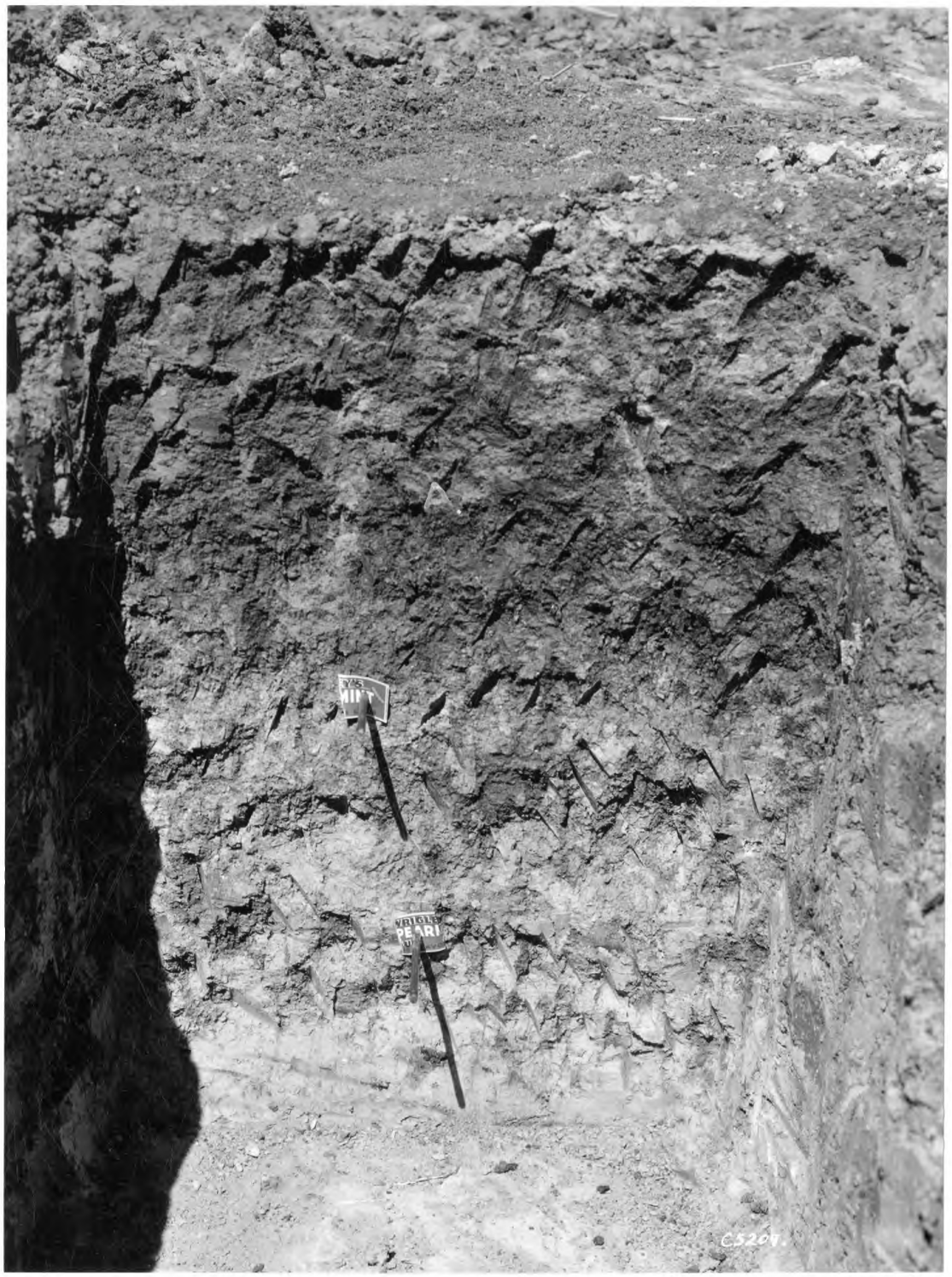
B. 7"-24" An exceedingly heavy, sticky, and nearly impervious layer. Color, steel gray. Almost devoid of structural development but showing a tendency to break into large, irregular clods. Texture, clay loam. Brown stain apparent in A is almost totally absent in B. Strong effervescence with HCl.

C. 25"+ A relatively loose, friable horizon, separated from the B horizon by a sharp line of demarcation. Color, light gray. Effervesces very strongly with HCl. Texture, clay loam, but containing more coarse particles than the B horizon.

Plate II

Photograph of the Profile of the "Slick Spot."

PLATE II



EXPERIMENTAL RESULTS

In an attempt to determine the cause of the poor physical condition and the infertility of the "slick spot" soil, determinations of soluble salts, reaction, replaceable bases, total nitrogen, and organic carbon were made with samples of unfractionated soils. In addition the colloid fraction was extracted from a sample from each horizon of the two soils and the SiO_2, R_2O_3 and base exchange capacity of the colloid determined.

Soluble Salts

In Table 1 are presented the results of the determinations of the water-soluble constituents of the "slick" soil and normal soil. Qualitative tests for the various soluble constituents were made but only nitrates and bicarbonates (HCO_3) were present in more than very small amounts. However, the amount of nitrates and bicarbonates in the "slick" soil seemed wholly insufficient to account for its infertility and the soluble salts were therefore, not fractionated.

Table 1. Water-soluble Constituents and pH Values of Normal Soil and "Slick Spot."

(Water-soluble constituents expressed as parts per million of air-dry soil)

	Normal soil				"Slick spot"		
Horizon	A	B_1	B_2	C	A	B	C
Total soluble salts	205.0	161.7	190.0	206.7	765.0	1090.0	1821.6
pH values	5.75	5.76	5.84	6.01	7.62	8.56	8.73

While the soluble salts of the "slick spot" are not present in sufficient concentration to be considered as directly responsible for the infertility of the soil, there is a distinct difference in the salt content of the various horizons of the two soils. The total soluble salts in all horizons of the "slick spot" were considerably higher than those of the normal soil. Since the highest concentration reported is not higher than the amount of nitrates, expressed as NO_3, in central Kansas soils fallowed during a hot and fairly dry summer, it was concluded that fractionation of the total soluble salts would not contribute greatly to the search for the cause of the infertility of the soil.

The pH values of the various horizons of both soils are also presented in Table 1. The results are an

indication of an important difference in the two profiles. They show an alkaline reaction in all horizons of the "slick spot." Since the quinhydrone electrode is inaccurate and yields progressively lower values than the true reaction above pH 7.5, it is probable the values presented are lower than the true values for this profile. The probable cause for the alkaline reaction will be discussed in a later paragraph.

Replaceable Bases

Table 2 shows the content of replaceable bases in both profiles. It is strikingly evident that the amount of each of the exchangeable bases is much higher in the "slick spot" than in the normal soil. The data show an increase of all exchangeable bases from the surface layer down to the lowest layer, except that of replaceable sodium in the "slick spot" which remains fairly constant. The results obtained in California (26) show a similar relationship.

The divalent bases are much more abundant in the "slick spot" than in the normal soil. This may be the result of several factors; namely, (a) lateral seepage which brings the calcium and magnesium compounds from a higher level in the slope and deposits them in this spot, (b) upward seepage of ground water which brings the salts up to the

Table 2. Replaceable Bases of Normal Soil and "Slick Spot."

(Milligram-equivalents per 100 grams of soil)

	Normal soil				"Slick spot"		
Horizon	A	B_1	B_2	C	A	B	C
Ca	11.1	12.7	11.3	14.6	14.6	20.4	28.1
Mg	4.8	7.9	5.69	7.1	9.2	11.4	11.0
K	0.78	0.91	1.01	1.04	1.23	1.49	1.71
Na	0.21	0.22	0.29	0.82	2.4	2.90	2.30
Sum of the exchangeable bases	16.89	21.73	18.29	23.56	27.43	36.19	43.11
Total exchangeable bases by Kappen method	22.8	26.00	30.4	35.5	32.8	34.8	51.95

higher layer from below, and (c) the divalent bases of the soil materials have not been subjected to leaching as in the normal soil.

It will be noted that in each instance a greater amount of exchangeable bases was obtained by the Kappen method than the sum of Ca + Mg + K + Na, except in the case of the B horizon of the alkali soil where the relationship was reversed. We should, theoretically, expect a lower amount of replaceable bases by individual determination

than by the Kappen method because of the presence of other bases such as Fe, Al, and Mn in the soil. The reason for the higher replaceable base content by the Kappen method in the B horizon of the alkali soil is not known. The discrepancy is probably due to analytical error. The comparative data by the two methods indicate, however, that there are probably no other replaceable bases than those determined individually present in such amounts as to be of great importance in determining the properties of the soil.

The relationship of each of the exchangeable bases to the sum of the Ca + Mg + K + Na is shown in Table 3 where each base is expressed as percentage of this sum. These data are also shown in Figure 1, where the relative proportions are more strikingly apparent than in the table.

Table 3. Relative Proportions of Exchangeable Bases (Percentages, based on sum of Ca + Mg + K + Na)

	Normal Soil				"Slick Spot"		
Horizon	A	B_1	B_2	C	A	B	C
Ca	65.71	58.44	61.78	61.96	32.22	56.37	65.18
Mg	28.42	36.35	31.11	30.14	33.54	31.50	25.49
K	4.62	4.19	5.52	4.41	4.48	4.14	3.96
Na	1.25	1.01	15.9	3.48	8.75	8.00	5.34

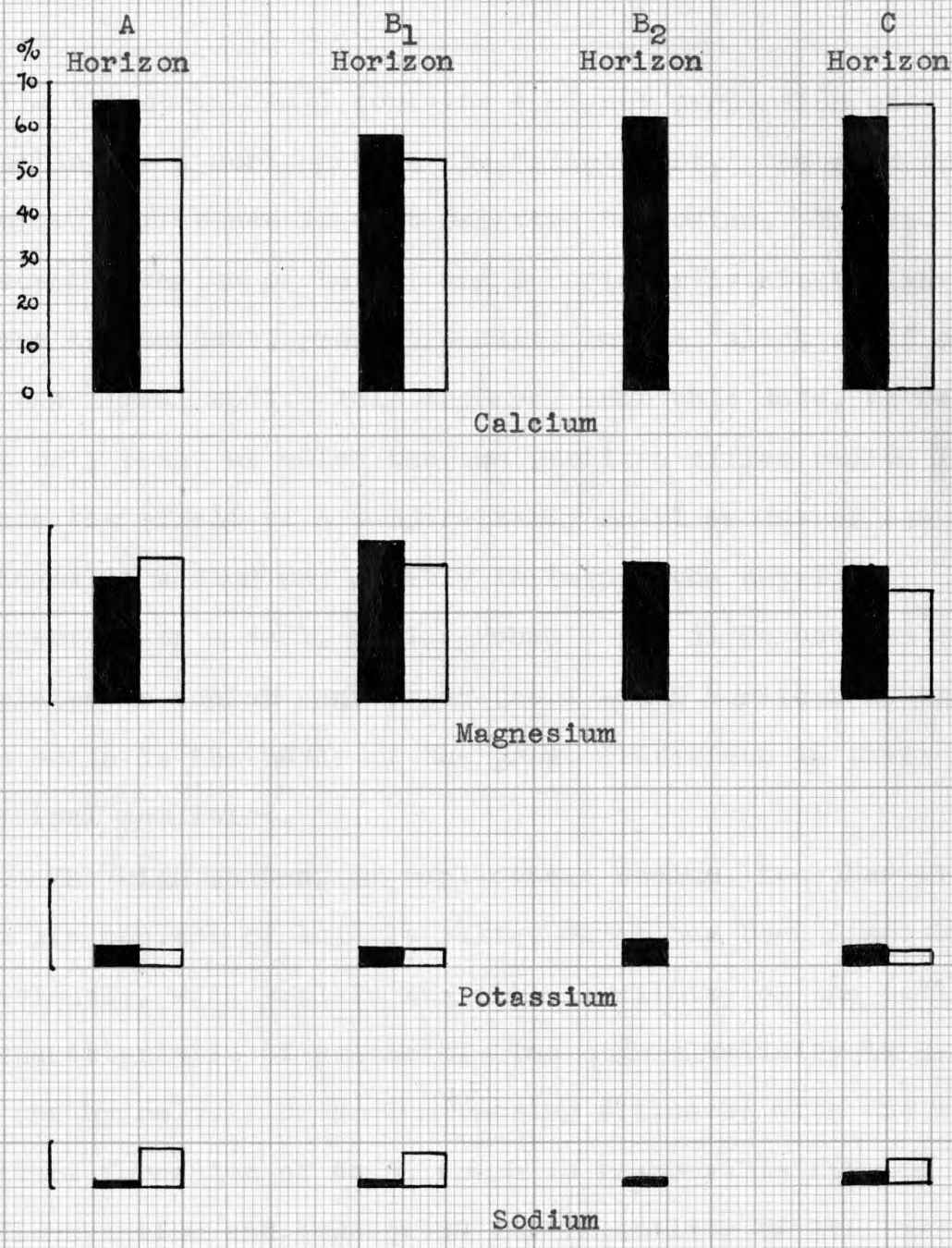


Fig. 1. Relative Proportions of the Exchangeable Bases in the Two Profiles. (Each Base Expressed as Percentage of the Sum of Ca+Mg+K+Na).

While the normal soil contains a higher proportion of calcium in the A horizon than the "slick spot," the most pronounced difference is that relating to sodium. The replaceable sodium of both A and B horizons is about eight times as abundant, proportionally, in the "slick spot" as in the normal soil. This appears, from this data, to be the only point at which the two profiles differ radically. Since the effect of a comparatively small amount of exchangeable sodium may greatly influence the physical properties of a soil, it is probable the difference in the replaceable sodium content of the A and B horizons of the two soils is the basis of the great difference in their physical condition.

The high content of replaceable sodium, together with the low content of soluble salts, which has been discussed previously, will explain the high alkalinity of the soil, a characteristic of solonetz. The high alkalinity is due to the hydrolysis of sodium bearing silicates with the resultant formation of NaOH, which is responsible for the deflocculation and consequent impermeability of the soil. Thus, a high concentration of hydroxyl ion is produced which is more toxic to plants than the hydrogen ion.

Total Nitrogen and Organic Carbon

The total nitrogen content of alkali soils is almost invariably low and this "slick spot" is no exception, as is well illustrated in Table 4. These results are in agreement with those of previous investigations with soils of this nature. The low content of nitrogen is the natural result of the sparse vegetative cover which the soil supports and the unfavorable conditions for free nitrogen fixation in the soil.

Table 4. Nitrogen and Organic Carbon of the Normal and "Slick Spot" Profiles

(Expressed as percentage of the air-dry soil)

	Normal soil				"Slick spot"		
Horizon	A	B_1	B_2	C	A	B	C
Total nitrogen %	0.112	0.07	0.04	0.03	0.098	0.031	0.021
Organic carbon %	1.04	0.30	0.163	0.038	0.213	0.105	0.000
C/N ratio	9.24	4.55	4.66	1.4	2.17	3.39	0.000

The organic carbon content of each of the various horizons of the "slick spot" is lower than that of the normal soil. Although the same is true with the nitrogen, the difference of the nitrogen content of the two profiles is much less marked than the difference in the organic carbon

content.

The relationship of carbon to total nitrogen as expressed in the carbon-nitrogen ratio is also shown in the table. The differences in the two profiles are very pronounced, the carbon-nitrogen ratios of the alkali soil being much narrower than those of the corresponding normal soil. The carbon-nitrogen ratios obtained for the normal soil closely agree with those found by Anderson and Byers (1) for profiles of soils of the Prairie Soils group. The writer is unable to offer an adequate explanation for the abnormally narrow carbon-nitrogen ratios of the "slick spot."

Silica, R_2O_3, and Base Exchange Capacities of the Colloid Fractions

It has been demonstrated by many soil investigators that within the range of colloidal dimensions, the higher the ratio of silica (SiO_2) to sesquioxides ($Al_2O_3 + Fe_2O_3$), the greater the manifestation of colloidal properties, i.e., absorptive capacity, stickiness, plasticity, base-exchange capacity, and other similar properties. Therefore, colloids with high silica-sesquioxide ratios, when dispersed, form very sticky, plastic soil layers not easily penetrated by roots or water.

The silica-sesquioxide ratios for the colloids of the profiles of the two soils were not calculated in this work since the substances precipitated by ammonia (R_2O_3) in the filtrate from the silica determinations were not fractionated. The relative SiO_2 and R_2O_3 values, however, indicate quite clearly the differences in the manifestation of plasticity, cohesiveness, and other similar properties on the part of the colloids of the two profiles.

The SiO_2 and R_2O_3 contents of the colloid fraction of each of the various horizons of the two profiles are shown in Table 5. It is evident that the silica content is higher and the R_2O_3 content lower in nearly all cases in the "slick spot" soil than in the normal soil.

Table 5. Silica and R_2O_3 Content of the Colloid Fraction of Each of the Various Horizons of the Normal and "Slick Spot" Profiles

(Expressed as percentage of oven-dry colloid)

	Normal soil				"Slick spot"		
Horizon	A	B_1	B_2	C	A	B	C
SiO_2	55.95	53.76	57.4	59.29	61.6	58.36	60.34
R_2O_3	43.21	37.43	33.95	32.75	35.35	35.51	39.27

It will be observed also that the SiO_2 content of the normal soil increases from the surface downward, while that of the

"slick spot" shows a tendency to decrease. The R_2O_3 content, on the contrary, decreases from the surface downward in case of the normal soil and increases in the "slick spot." The chemical nature of the colloid fraction of the alkali soil as revealed here, when considered together with its content of replaceable sodium, offers an explanation for the tight, impervious nature of the profile.

In Table 6 is presented the base-exchange capacity of the colloid fraction of each horizon of the two profiles.

Table 6. Base-exchange Capacities of the Colloid Fractions

(Milligram-equivalents per 100 grams of colloid)

	Normal soil				"Slick spot"		
Horizon	A	B_1	B_2	C	A	B	C
Base-exchange capacity	45.0	55.0	63.9	67.8	68.5	85.0	80.0

In all cases the colloids of the "slick spot" show a much higher base-exchange capacity than the colloids of the corresponding horizons of the normal soil. The relative SiO_2 and R_2O_3 values in Table 5 suggest some such differences in base-exchange capacities as are revealed here.

Materials Extracted by Water During the Separation of the Colloid Fractions

When the soil suspensions siphoned off of the soil-water mixture in the churn had been centrifuged and filtered through Pasteur-Chamberland filter cones, the colloid-free water extract was in some cases colored. In order to determine the cause of this color, the R_2O_3 constituents and organic matter of samples of the extracts were determined. The results are reported in Table 7. The data show that the quantities of soluble R_2O_3 constituents of the samples, as determined from water extracts, are higher in the normal soil than in the "slick spot." Therefore, the induration in this soil must be attributed to factors other than the presence of soluble iron and aluminum.

Table 7. R_2O_3 Constituents and Organic Matter Extracted from Soil Samples by Water During the Churning Process in the Separation of the Colloid Fractions

(Expressed as percentage of air-dry soil)

	Normal soil				"Slick spot"		
Horizon	A	B_1	B_2	C	A	B	C
R_2O_3	0.02	0.013	0.008	0.001	0.005	0.01	trace
Organic matter	trace	trace	trace	trace	0.1	trace	trace

Traces of soluble organic matter were found in all horizons but only in case of the A horizon of the alkali soil was a measurable amount detected. Here 0.10 per cent was found, which is equivalent to 2000 pounds per 2,000,000 pounds of soil. This accounts for the brown stains on the soil particles of the A horizon of the "slick spot" soil. The presence of this soluble organic matter lends convincing weight to the theory of the hydrolysis of Na-clays in the soil, with the production of NaOH as the source of the soil's alkalinity. The occurrence of this hydrolysis reaction also explains the poor physical condition and infertility of the soil. The presence of the soluble organic matter is one of the characteristics of this spot relating it to the solonetz type of soil and also to the black alkali group.

Mechanical Analysis

The physical constitution of a soil determines, largely, the general characteristics of the soil profile. A high content of particles of colloid size together with a relatively high replaceable sodium content results in a poor physical condition of the soil. In reality, this question is important and fundamental since many alkali soils of the type which have low soluble salt content are high in percentage of colloidal particles. In order to

throw further light on this important question, mechanical analyses of samples of the various horizons of the soil profiles were made. The analytical data are presented in Table 8 and are shown graphically in Figure 2.

The relative amounts of the soil fractions from both normal and "slick spot" soils do not vary a great deal. In general, the finer soil particles in the "slick spot" are more abundant than in the corresponding horizons of the normal soil. The differences are not marked except that the total sands of the B horizon of the alkali soil are much lower and the silt much higher than in any other horizons of either profile. Such differences in the relative amounts of fine particles in the two soils would be sufficient to produce a noticeable difference in the physical constitution of the two soils, even though the particles of each soil were flocculated. However, the contrast would certainly not be marked. Moreover, the clay and colloid contents of the "slick spot" soil are considerably lower than those of many normally developed soils in Kansas. When the amounts of fine textured particles present in the various horizons of the "slick spot" soil, however, are deflocculated under the influence of the hydrolysis of sodium-bearing silicates, a soil with decidedly bad physical condition results.

Table 8. Mechanical Analyses of Samples from the Various Horizons of the Normal Soil and "Slick Spot."

(Expressed as percentage of the mineral fraction of the soil)

		Sand Fractions									
		2.0-1.0 mm.	1.0-.5 mm.	.5-0.25 mm.	.25-.1 mm.	.1-.05 mm.	Total sands	Silt	Clay	Colloid	Solution loss (% of oven-dry soil)
Normal Soil	A	0.03	0.39	2.14	11.18	18.76	32.5	39.44	28.07	25.59	2.95
	B_1	0.00	0.41	1.63	13.37	16.24	31.65	33.86	34.49	33.41	1.61
	B_2	0.05	0.46	2.76	13.25	16.68	33.20	38.42	28.37	26.31	0.41
	C	0.00	0.23	1.38	10.14	16.46	29.21	41.84	29.95	24.77	0.20
"Slick Spot"	A	0.16	0.33	1.52	9.72	22.43	34.16	32.54	33.3	31.74	1.17
	B	0.92	0.15	0.18	0.98	8.04	10.27	52.95	36.76	35.92	1.11
	C	0.97	0.44	0.53	1.91	25.51	29.36	39.96	30.67	25.45	0.43

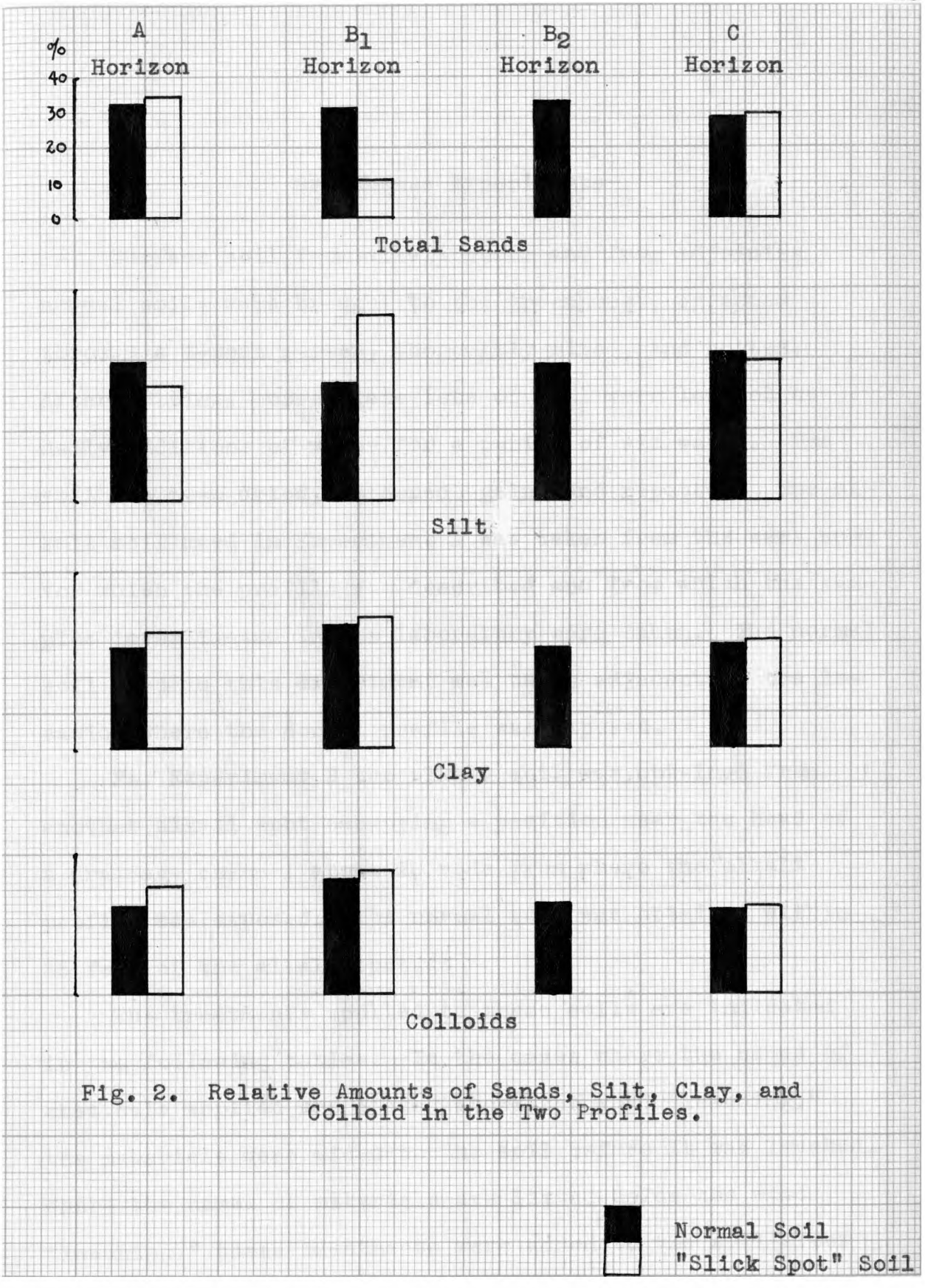


Fig. 2. Relative Amounts of Sands, Silt, Clay, and Colloid in the Two Profiles.

Greenhouse Experiments

Surface soil from alkali spots and from adjoining normal soils were brought to the greenhouse, screened through a 4-mesh screen, thoroughly mixed, and potted. After potting, appropriate lots of soil were leached by daily additions of water for a period of six weeks. The soil was then dried, screened again, and repotted. The alkali soil used in Experiment 1 was taken from the same spot for which the profile was described and from which the samples investigated in the laboratory were taken. The normal soil used in this experiment was taken adjacent to the location where the normal profile was exposed.

For Experiment 2 the alkali soil was obtained from another alkali spot occupying a position near the head of a drainage channel about 20 rods from where the alkali profile was exposed. The normal soil was obtained within 35 feet of the alkali spot.

The treatments applied to these soils are indicated in the following tables. In the cases where the names of chemicals applied are listed above the word "leaching," the materials were added to the soil before it was leached. Where the names of materials are listed below the word "leaching," these treatments were added to the soil after the leaching process was completed.

In each experiment Kansas common alfalfa seed was planted at the rate of about 30 seeds per pot. After the plants reached a height of about 3 inches, they were thinned to 14 plants per jar in the case of Experiment 1 and 6 plants per jar in Experiment 2.

Table 9 illustrates the effect of various treatments on the yield of alfalfa. Applications of gypsum in amounts of 10 to 15 tons followed by leaching, gave the best results. The yields on alkali soils treated in this manner were even higher than the highest yields obtained on normal soil. Alkali soil treated with 15 tons of gypsum, leached, and fertilized with superphosphate and sodium nitrate gave the highest yield but gypsum and leaching alone, was nearly as effective. Moreover, 10 tons of gypsum per 2,000,000 pounds of soil in this type of treatment was practically as effective as 15 tons. The data obtained indicate the possibility of completely reclaiming the soil of such spots by the application of gypsum and leaching, provided drainage can be provided and seepage prevented after such reclamation.

The application of sulfur was not as effective as the use of gypsum. Growth failed entirely in the jars treated with sulfur and the cause, as indicated by the pH values of the soils three months after planting alfalfa, was the de-

Table 9. The Yield of Alfalfa as Affected by the Various Treatments.

(Experiment 1)

	Nos. of jars	Treatment and quantity added per 2,000,000 pounds of soil	Weight in grams per pot (Average of duplicates) First cutting	Second cutting	Third cutting	Total	pH values three months after alfalfa was planted
"Slick Spot" Soil	1	Gypsum, 15 tons Leaching	7.4	10.95	13.0	31.35	6.6
	2	Gypsum, 15 tons Leaching Superphosphate, 180 pounds	8.1	11.65	13.4	33.15	6.8
	3	Gypsum, 15 tons Leaching Superphosphate, 180 pounds $NaNO_3$, 200 pounds	7.75	12.3	13.4	33.45	6.75
	4	Gypsum, 10 tons Leaching	7.45	10.6	12.8	30.85	6.85
	5	Sulfur, 1800 pounds Leaching $CaCO_3$ (3 mo.later) 5 tons	7.45	5.9	7.6	13.5	3.19 5.6 (after liming)
	6	Sulfur, 3600 pounds Leaching $CaCO_3$, 2 tons $CaCO_3$ (3 mo.later) 3 tons	7.45	5.6	7.8	13.4	4.13 5.71 (after liming)
	7	Sulfur, 3600 pounds Leaching $CaCO_3$ (3 mo.later) 5 tons	7.45	4.95	7.8	12.75	3.13 4.95 (after liming)
	8	Sulfur, 1000 pounds Manure, 18 tons Leaching	2.65	5.25	5.3	13.20	4.66
	9	Manure, 18 tons Leaching	7.85	7.8	7.3	22.95	6.52
	10	Leaching with distilled water	4.3	6.35	7.0	17.65	7.45
	11	Leaching with tap water	5.95	7.45	7.3	20.7	7.53
	12	Superphosphate, 180 pounds No leaching	3.8	5.0	6.2	15.00	7.45
	13	$CaCO_3$, 5 tons No leaching	6.25	7.0	8.7	21.95	7.65
	14	Untreated	3.2	3.5	4.0	10.7	7.8
Normal Soil	15	Superphosphate, 180 pounds No leaching	7.55	8.15	10.2	25.9	6.52
	16	Superphosphate, 180 pounds $NaNO_3$, 200 pounds No leaching	8.4	9.95	11.0	29.35	6.73
	17	Untreated	7.95	8.2	8.4	24.55	6.9

velopment of an excessive degree of acidity. The sulfur undergoes oxidation in the soil with the formation of H_2SO_4, which changes the reaction of the soil in the direction of greater acidity. The application of an excessive amount of sulfur to soils causes the development of extreme acidity with consequent unfavorable conditions for growth of the alfalfa. At the time of the first cutting in the remaining jars, the sulfur pots were treated with lime and replanted. At the succeeding cuttings, the yields in these pots were higher than those of the untreated pots, indicating that the use of sulfur in moderate applications with leaching may be an effective method of reclamation.

Next to gypsum, manure alone with leaching was the most successful treatment. Manure with sulfur failed to produce satisfactory results, presumably because of the acidity developed in the soil. Leaching with either distilled water or tap water greatly improved the soil but fell far short of the effectiveness of the gypsum and leaching treatment. Tap water was somewhat more effective than distilled water, very probably because of the calcium salts carried by the former. Lime applied without leaching at the rate of 5 tons per 2,000,000 pounds of soil doubled the yields of alfalfa as compared to untreated soil.

The rather pronounced beneficial effect of the application of lime unaccompanied by leaching was somewhat

surprising, although the use of lime has been recommended by various investigators as having some value in alkali soil reclamation. It is probable the heavy lime application benefitted the soil in at least two ways, i.e., (a) it produced some flocculation or aggregation of the particles and thereby improved the physical condition of the soil, and (b) it precipitated the soluble organic matter which undoubtedly was toxic to growing plants.

Superphosphate produced an increase in yield of alfalfa when applied to unleached alkali soil but the increase was much less than that produced by the best treatments. Leached alkali soil gave only slightly higher yields when treated with superphosphate than when not so treated. On the normal soil, it increased the yield of the crop only by a small amount.

The results obtained in Experiment 2 are shown in Table 10. The pots used in this experiment were small in size and only six alfalfa plants were allowed to grow in each pot. Therefore, the yields per pot are smaller than in Experiment 1. Each treatment applied to the alkali soil improved its productivity although the yield increases produced by superphosphate alone are hardly significant. The best results were obtained in pots treated with 50 per cent of sand (by weight) and not leached, followed by lime with leaching and gypsum also with leaching. Here again, as in

Table 10. Yields of Alfalfa as Affected by the Various Treatments

(Experiment 2)

	Nos. of jars	Treatment and quantity added per 2,000,000 pounds of soil	Weight in grams per pot (Average of duplicates) First cutting	Second cutting	Total
"Slick Spot" Soil	1	Sulfur, 250 lbs. leaching	1.9	2.9	4.8
	2	Sulfur, 500 lbs. leaching	1.75	2.3	4.05
	3	Sulfur, 1000 lbs. leaching	1.35	2.2	3.55
	4	$CaCO_3$, 5 tons leaching	3.00	2.8	5.8
	5	Superphosphate, 200 lbs. No leaching	1.2	1.3	2.5
	6	Gypsum, 5 tons leaching	2.4	2.6	5.0
	7	Sand, 15 per cent No leaching	2.0	2.1	4.1
	8	Sand, 30 per cent No leaching	2.0	2.0	4.0
	9	Sand, 50 per cent No leaching	3.1	3.4	6.5
	10	Untreated	0.9	1.1	2.0
Normal Soil	11	Untreated	2.3	2.6	4.9
	12	Superphosphate	2.2	2.5	4.7

Experiment 1, the pots treated with gypsum outyielded the sulfur pots, indicating that sulfur must be used with caution in alkali reclamation in order to avoid harmful acidity. The relatively light application of gypsum was not as effective as 50 per cent sand which indicates that lighter applications of gypsum are probably not as satisfactory as applications of 10 tons or more per 2,000,000 pounds of soil. Sand added to the alkali soil in amounts equal to 15 per cent and 30 per cent by weight doubled the yield of the untreated soil but a 50 per cent sand application tripled the yield. The sand improved the physical condition of the soil, permitted aeration, and diluted the soil mass. It is probable these three factors completely account for its beneficial effect.

Difficulty would be encountered in attempts at using in the field the most successful treatments in the greenhouse experiments. The spots are so located in many instances that leaching would be difficult or impractical. Unless precautionary measures were employed, the seepage of ground water would again contaminate the soil after the reclamation process. The results of the greenhouse experiments indicate that heavy applications of lime or manure or the incorporation of a considerable amount of sand in the surface soil would be effective. The presence of the very

heavy subsoil below and the ever recurring movements of seepage water, however, would decrease the effectiveness of such treatments in the field as compared to greenhouse conditions. These treatments, nevertheless, appear to offer the most promise of restoring such spots to a state of productivity. Maintenance of straw or sand mulches to check evaporation might also prove beneficial.

SUMMARY

1. A study has been made of the comparative physical and chemical properties of an alkali spot and an adjoining normal soil.

2. A typical alkali spot of soils of humid climate, often designated as a "slick spot," which is located in Field 3, Block B of the Agronomy Farm of the Agricultural Experiment Station, was chosen for investigation. Two holes were dug, one in the "slick spot" and the other in the normal soil about 50 feet apart. The various horizons were differentiated and thorough observations of the physical properties of both profiles were made.

3. The results of the profile studies indicate the existence of striking differences between the two soils. The heavy and deflocculated nature of the surface soil and the occurrence of a gray, hard, impervious layer, a true

hardpan in the subsoil were the most outstanding features of the "slick spot" soil.

4. Soluble salts are not present in sufficient concentration to be considered as directly responsible for the infertility of the "slick spot" soil.

5. The pH values of the soils indicated an important difference in the two profiles. The "slick spot" soil showed an alkaline reaction in all horizons while the normal soil was acid in the A and B horizons and showed an alkaline reaction only when the parent materials were encountered.

6. The total exchangeable base content is higher in the "slick spot" soil than in the normal soil. The percentage of replaceable sodium in the latter is much lower than in the alkali soil.

7. The high replaceable sodium and low water soluble salts explain the high alkalinity of the "slick spot" soil. High alkalinity is probably due to the hydrolysis of sodium silicates with the formation of NaOH. Further evidence of the formation of NaOH is found in the presence of 0.10 per cent of water soluble organic matter in the A horizon of this soil.

8. The total nitrogen and organic carbon contents of the alkali soil are lower than those of the normal soil. The former shows considerably narrower carbon-nitrogen

ratios than the latter.

9. The analyses of the colloid fractions show a higher percentage of SiO_2 and lower R_2O_3 in the "slick spot" soil than in the normal soil. An increase in the percentage of SiO_2 and decrease of R_2O_3 from the surface layer to the lower layers occurs in the case of the normal soil, while in the case of the alkali soil the reverse is true.

10. The base-exchange capacities in all samples are considerably higher in the "slick spot" soil than in the corresponding samples of the normal soil.

11. In general, the finer soil particles in the "slick spot" are more abundant than in the corresponding horizons of the normal soil. The differences in the relative amounts of fine particles in the two soils are sufficient to produce a noticeable difference in their physical constitutions, but the marked difference in the profiles is attributable to the deflocculated state of the particles in the alkali soil.

12. Several materials were applied to the alkali soil under greenhouse conditions and some have produced marked improvement in the productivity of the soil.

13. Gypsum treatment with leaching has given the best results while stable manure with leaching and lime ($CaCO_3$) without leaching increased yields of alfalfa on this soil

in the order mentioned.

14. Applications of gypsum, stable manure, and lime at the rate of 15 tons, 18 tons, and 5 tons per 2,000,000 pounds of soil, respectively, produced marked improvement.

15. Leaching without the application of other materials resulted in a higher yield of alfalfa than was obtained on unleached and untreated soil, but leaching alone was not altogether satisfactory.

16. Treatment with sulfur and leaching was not successful because the soil was rendered strongly acid by the treatment. Lighter applications of sulfur than were used might have proved beneficial.

17. Treatments with 15 per cent, 30 per cent, and 50 per cent of sand have resulted in marked improvement of the alkali soil but 50 per cent of sand proved the most effective of the three rates of application.

18. Both normal and alkali soils responded slightly to superphosphate treatment.

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